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TEMAWS II

UNITED STATES ARMY

COMBINED ARMS CENTER

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COMBAT DEVELOPMENTS ACTIVITY

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Fort Leavenworth, Kansas 66027

TACTICAL EFFECTIVENESS OF MINEFIELDS IN THE ANTIARMOR WEAPON SYSTEM MINE DETECTION SIDE TEST

TEMAWS II

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper contains an analysis of the data collected during the Mine Detection Side Test of the Tactical Effectiveness of Minefields in the Antiarmor Weapon System (TEMAWS) field experiment. The purpose of the test was to collect data on the ability of tank drivers to detect and avoid scatterable mines as a function of varying levels of vehicle speed, minefield density and mine detectability. A trial consisted of one tank, manned only with a driver, traversing a course of four minefields of different densities. The drivers were not task

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loaded beyond the objective to detect and avoid all mines. Results of the analysis include probabilities of mine detection, detection and avoidance, and mine encounter. Distances traveled to first detection and between subsequent encounters are also provided. Analysis of variance conducted on the independent variables identified significant factors and interacting factor effects.

FOREWORD

This analysis was conducted by the Test Plans and Data Management Branch of the Combat Operations Analysis Directorate (COAD) of the US Army Combined Arms Combat Developments Activity (CACDA). Data derived from the analysis are to be used in the Cost and Operational Effectiveness Analysis for the Family of Scatterable Mines (FASCAM COEA) being conducted by CACDA. The work was performed during the period February to April 1977. I would like to acknowledge the continuing contributions of Mrs. Rosalie Fulks without whom this report would still be in handwritten form.

ABSTRACT

This paper contains an analysis of the data collected during the Mine Detection Side Test of the Tactical Effectiveness of Minefields in the Antiarmor Weapon System (TEMAWS) field experiment. The purpose of the test was to collect data on the ability of tank drivers to detect and avoid scatterable mines as a function of varying levels of vehicle speed, minefield density, and mine detectability. A trial consisted of one tank, manned only with a driver, traversing a minefield course. The drivers were not task loaded beyond the objective to detect and avoid all mines. Results of the analysis include probabilities of mine detection, detection and avoidance, and mine encounter. Distances traveled to first detection and between subsequent encounters are also provided. Analysis of variance conducted on the independent variables identified significant factors and interacting factor effects.

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1. INTRODUCTION. The purpose of this report is to present the results of the Tactical Effectiveness of Minefields in the Antiarmor Weapon System Scatterable Mine Detection Side Test (TEMAWS II). The experiment was conducted by the Combat Developments Experimentation Command at Fort Hunter Liggett during February 1977.

2. PURPOSE AND OBJECTIVES.

a. Purpose. The purpose of the TEMAWS II test was to obtain data on the ability of tank drivers to detect and avoid scatterable mines as a function of varying levels of vehicle speed, minefield density, and mine detectability. No attempt was made to task load the drivers beyond the primary purpose of detecting and avoiding mines.

b. Objectives. The two objectives of the experiment were as follows:

- Determine an estimate of the probability of detecting and the probability of avoiding mines, given the knowledge of a minefield, as a function of vehicle speed, minefield density, and mine detectability.

- Determine the distance traveled before the first mine detection under the same conditions.

3. SCOPE AND LIMITATIONS. Each trial consisted of a single tank passing through one minefield and attempting to avoid all mines. There was no attempt to task load the driver. The test was not instrumented; as a result, exact position-location data for each detection and encounter were not collected. These distances were measured manually by data collectors at the end of each trial. The noninstrumentation of the test also made it impossible to determine if all detections reported by the drivers actually were mines or only what the drivers perceived to be mines. Trials were conducted at speed levels of 3 to 5, 6 to 9, and 10 to 12 miles per hour through minefields at three distinct density levels: .001, .003, and .01 mines per square meter. Each of these factor combinations was conducted at both a high and a low level of mine detectability. Figures 1 and 2 illustrate the employment of these two levels of detectability. Due to the sparse vegetation and relatively flat terrain on which the trials were conducted, the data collected for these detectability levels are inherently biased upwards. Any use and interpretation of these data should take this into consideration.

Figure 1. High detectability level minefield

Figure 2. Low detectability level minefield

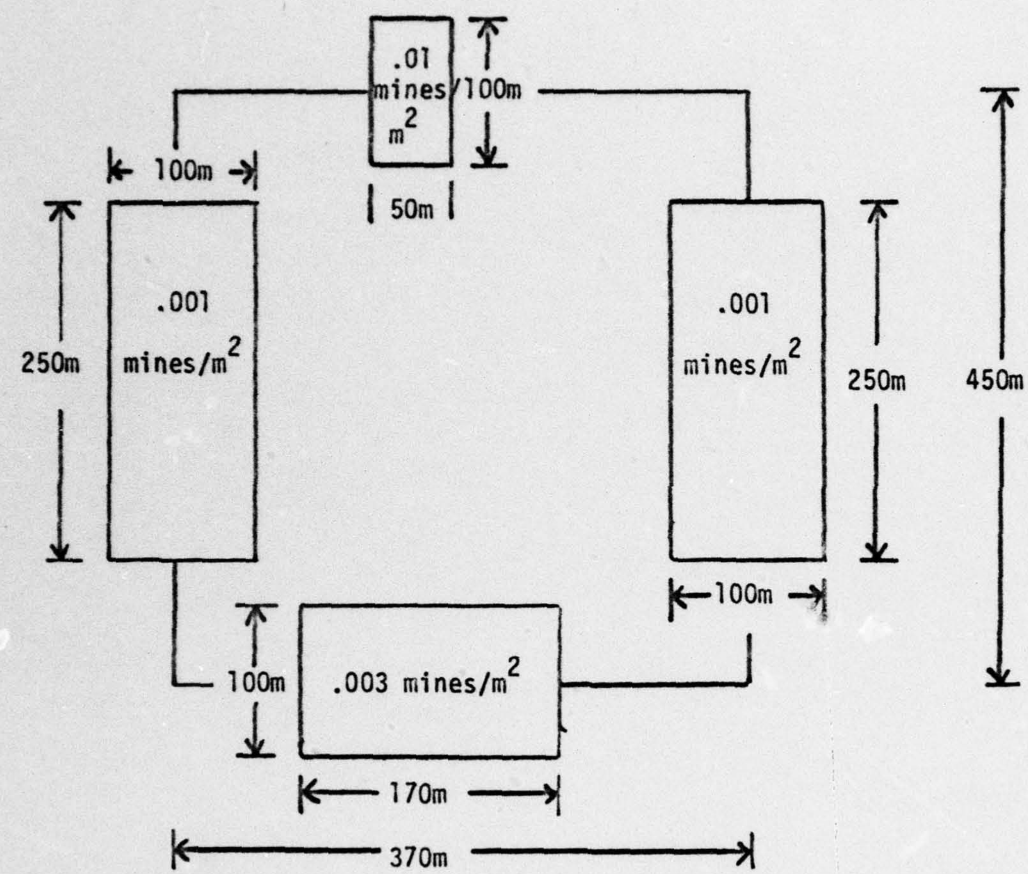

Figure 3. TEMAWS II minefield course

4. DATA DESCRIPTION.

a. Definition of Terms.

(1) Mine detection. A mine was recorded as detected if the driver visually detected the mine and changed direction to avoid it or if he visually detected the mine but was unable to change direction in time to avoid it.

(2) Mine encounter. A mine was recorded as encountered if it was found to be under the track or belly portion of the tank's actual path in the minefield.

(3) High detectability level. Mines were placed on top of the ground with no deliberate cover.

(4) Low detectability level. Mines were purposely covered with either dirt or grass.

b. Conduct of Trials. For each trial a driver was instructed to traverse a minefield, as depicted in figure 3, attempting to avoid all mines while maintaining a specified speed. A data collector rode with each driver and marked the location of the tank at first mine detection by dropping a marker from the tank. Thereafter, the driver called out "mine" for every mine detected in his path. The number of mines called out was recorded by the data collector. Two additional data collectors followed each tank through the minefield and recorded the perpendicular distance from the minefield edge to the marked location of first mine detection, the actual path length of the vehicle, the number of mines encountered, and the distances between subsequent encounters along the path.

c. Design Matrix. The design matrix in table 1 shows the actual number of trials run for each trial cell.

Table 1. TEMAWS II design matrix

density (mines/m^2) / speed (mph)	HIGH DETECTABILITY			LOW DETECTABILITY		
	.001	.003	.01	.001	.003	.01
3-5	26*	13	54	53	26	26
6-9	51	27	22	49	25	26
10-12	53	25	21	24	13	61

* Number of minefields per trial cell.

5. ANALYSIS METHODOLOGY.

a. Probability Formulas. The estimates for the probability of detecting a minefield, probability of detecting and avoiding a mine, and probability of encountering a mine were derived as follows:

(1) P_{MFD} = probability of detecting a minefield

$$= \frac{x}{N} \qquad \text{(eq 1)}$$

where N = total number of minefields (trials) for a given cell of the design matrix

x = number of minefields in which mines were detected

(2) P_{DA} = probability of detecting and avoiding a mine in a tank's path

$$= \left[\sum_{i=1}^{N} \frac{D_i}{D_i + E_i} \right] /N \qquad \text{(eq 2)}$$

where D = number of mines detected in a path

E = number of mines encountered in a path

N = total number of trials

The rationale for the approach in equation 2 is that the total number of mines that were available for detection and avoidance were not only those that were detected but also those that were encountered by the tank. A basic assumption made, which may have biased the results, was that each mine detected was also avoided. In fact, this may not have occurred due to the definition established in paragraph 4a(1). However, it gave the best estimate available from the data.

(3) P_E = probability of encountering a mine

$$= \frac{y}{N} \qquad \text{(eq 3)}$$

where N = total number of minefields (trials) for a given cell of the design matrix

y = number of minefields in which a mine was encountered

b. A Posteriori Tests. Following these calculations a 3x3x2 analysis of variance (ANOVA) was conducted to determine if the main factors of vehicle speed, minefield density, and mine detectability or their interactions had a significant effect on the resultant probability estimates. If the main factors proved significant at the α = .05 level of significance, the Scheffé method of contrasts was used. Significant interactions were investigated by a simple effects analysis and graphic approach.

c. Additional Data. Additional data concerning number of minefields where no detections occurred and number of minefields that were detected prior to crossing the entrance line are presented for information. Also listed are the average distances between successive encounters for each factor combination. Cumulative plots illustrating the distances to first detection versus the distance to first encounter are presented to elucidate the effects that various factor combinations of speed and density have on these two events.

6. ANALYSIS RESULTS.

a. Probability Data. Tables 2, 3, and 4 contain the summary data for the estimates of probability of minefield detection, probability of detecting and avoiding a mine in a tank's path, and probability of mine encounter, respectively. With each probability estimate is the number of trials that were conducted in that matrix cell.

b. Analysis of Variance Results. A 3x3x2 ANOVA was conducted on each probability matrix. The estimate for the probability of detecting a minefield and the probability of encounter are only single observations for each matrix cell. An ANOVA could only be conducted if some of the interactions were assumed to be zero. For both cases the three factor interaction was chosen with its mean square having expectation σ^2. This value was used as the error mean square in calculating the remaining F ratios. Individual factor mean squares were calculated in the normal manner with n=1 for each cell (ref 1). The results are shown in tables 5, 6, and 7. Significant factors (α = .05) are marked with an asterisk (*) beside the F ratio.

c. Scheffé Analysis. To determine which levels of the main factors were responsible for the significant F ratios in the ANOVA results, a Scheffé method of contrasts was used on the speed and density factors (ref 2). This test was not conducted for levels of detectability as the results were obvious from the data.

(1) In the probability of minefield detection data, contrasts involving the various density levels proved significant for all cases in which the .001 mines/square meter density level was considered. Inspection of the sums of the probabilities for each level showed the

Table 2. TEMAWS II probability estimate of minefield detection

density (mines/m^2) / speed (mph)	HIGH DETECTABILITY						LOW DETECTABILITY					
	.001		.003		.01		.001		.003		.01	
	P_{MFD}	N*	P_{MFD}	N	P_{MFD}	N	P_{MFD}	N	P_{MFD}	N	P_{MFD}	N
3-5	1.0	26	1.0	13	.981	54	.830	53	.654	26	.692	26
6-9	.980	51	.963	27	1.0	22	.816	49	.640	25	.692	26
10-12	.868	53	.760	25	.905	21	.792	24	.615	13	.639	61

* Number of minefields per trial cell.

Table 3. TEMAWS II probability estimate of detection and avoidance

density (mines/m^2) / speed (mph)	HIGH DETECTABILITY						LOW DETECTABILITY					
	.001		.003		.01		.001		.003		.01	
	P_{DA}	N*	P_{DA}	N	P_{DA}	N	P_{DA}	N	P_{DA}	N	P_{DA}	N
3-5	.962	26	.908	13	.757	54	.634	53	.558	26	.638	26
6-9	.866	51	.895	27	.788	22	.565	49	.467	25	.472	26
10-12	.712	53	.785	25	.683	21	.662	24	.488	13	.392	61

* Number of minefields per trial cell.

Table 4. TEMAWS II probability estimate of encounter

	HIGH DETECTABILITY						LOW DETECTABILITY					
density mines/m^2	.001		.003		.01		.001		.003		.01	
speed (mph)	P_E	N*	P_E	N	P_E	N	P_E	N	P_E	N	P_E	N
3-5	.0	26	.077	13	.333	54	.396	53	.654	26	.423	26
6-9	.039	51	.185	27	.136	22	.347	49	.560	25	.577	26
10-12	.226	53	.560	25	.571	21	.375	24	.385	13	.459	61

* Number of minefields per trial cell.

Table 5. ANOVA results for probability estimate of minefield detection

Source	SS	DF	MS	F
Detectability	.2418	1	.2418	219.1*
Speed	.0335	2	.0167	15.2*
Density	.0359	2	.0180	16.3*
Detect x Speed	.0109	4	.0027	2.5
Detect x Density	.0205	2	.0103	9.3*
Speed x Density	.0032	2	.0016	1.5
Detect x Speed x Density	.0044	4	.0011	
TOTAL	.3503	17		

Table 6. ANOVA results for probability estimate of detection and avoidance

Source	SS	DF	MS	F
Detectability	10.726	1	10.726	72.95*
Speed	1.613	2	.806	5.48*
Density	1.737	2	.869	5.91*
Detect x Speed	.507	4	.127	.86
Detect x Density	.125	2	.063	.43
Speed x Density	1.068	2	.534	3.63*
Detect x Speed x Density	-.234	4	-.059	-.40
Error	84.255	573	.147	
TOTAL	99.797	590		

Table 7. ANOVA results for probability estimate of encounter

Source	SS	DF	MS	F
Detectability	.2326	1	.2326	12.12*
Speed	.0567	2	.0283	1.48
Density	.1292	2	.0646	3.37
Detect x Speed	.1688	4	.0422	2.20
Detect x Density	.0179	2	.0090	.47
Speed x Density	.0021	2	.0011	.06
Detect x Speed x Density	.0768	4	.0192	
TOTAL	.6840	17		

.001 density to be considerably greater than the sums for the other two levels (5.29 at .001, 4.63 at .003, and 4.91 for .01). This same test conducted on the three speed levels had significant contrasts whenever the 10 to 12 miles per hour speed was involved, the resultant probability sum being significantly lower than the sums of the other speed levels.

(2) Tests on the three levels of speed in the probability of detection and avoidance gave significant contrasts whenever the 10 to 12 miles per hour level was used. Summation of the probabilities at this speed (114.8) was much lower than the 3 to 5 mile per hour speed (142.4) and the 6 to 9 mile per hour level with its 137.4 sum. When applied to the three density levels, five out of the six contrasts investigated proved to be significant. No one factor level was dominant.

d. Factor Interactions - Simple Effects Analysis. A factor interaction was present in both ANOVA results. To further explain the cause of the significance, a simple effects analysis (ref 3) was used. Figures 4 and 5 present graphic representations of the analysis results. Figure 4, the detectability x density interaction from the probability estimate of minefield detection table, shows, as do the analysis results, *that the* detectability level of the mines is the strongest influence in the interaction.

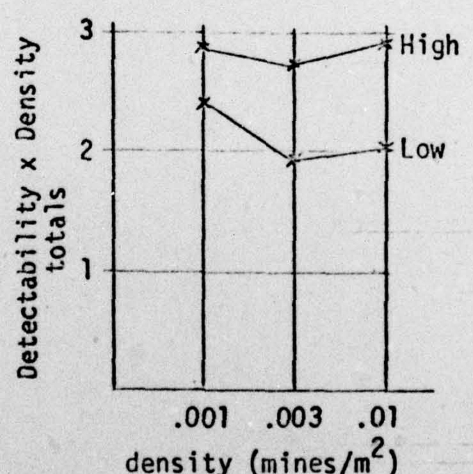

Figure 4. Probability estimate of minefield detection, detectability x density interaction

The density x speed interaction, which was significant for the probability estimate of detecting and avoiding a mine, is illustrated in figure 5. The analysis performed on each factor level combination proved significant; and, as seen in figure 5, no one factor was dominant at any level.

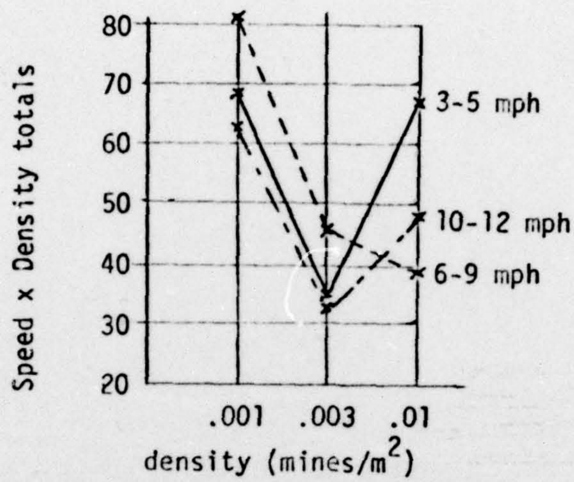

Figure 5. Probability estimate of detecting and avoiding a mine, speed x density interaction

e. Additional Results.

(1) The data presented in table 8 below are given for information purposes only. The table lists the total number of minefields (MF) for that trial cell, the number of minefields in which no detections (ND) occurred, and the number of minefields that were detected prior to crossing the entrance point (PD). A comparison of the values at each detectability level shows that at a high detectability level not only did detections occur in each trial (except at .001 density level; 10 to 12 miles per hour), but also a considerable number of trials had detections occur prior to entrance, particularly at the .01 density level. This prior knowledge may have contributed to the lower encounter probabilities at this factor level. In low detectability trials the number of prior detections dropped in all factor levels and the number of minefields in which no mines were detected increased.

Table 8. Minefield detection data

density mines/m^2 / speed (mph)	HIGH DETECTABILITY .001			.003			.01			LOW DETECTABILITY .001			.003			.01		
	MF	ND	PD	MF	ND	PD	MF	ND	PD	MF	ND	PD	MF	ND	PD	MF	ND	PD
3-5	26	0	16	13	0	6	54	0	22	53	1	0	26	4	1	26	5	5
6-9	51	0	9	27	0	5	22	0	10	49	4	3	25	4	0	26	3	7
10-12	53	5	8	25	0	6	21	0	12	24	1	2	13	4	0	61	18	5

(2) Figures 6 through 11 illustrate the effects of various factor level combinations on the distances traveled by a tank from the edge of the minefield until the first mine was detected and until the first mine was encountered. To account for those trials in which a mine was detected prior to crossing into the minefield (see table 8), a bias of 80 meters was added to each data point. This had the effect of shifting true zero on the x-axis to the 80-meter point. The means and standard deviations given with each figure were calculated prior to the addition of the 80-meter bias and represent the actual mean distances traveled.

(a) A comparison of the two graphs in figures 6, 7, and 8 further emphasizes the effects a given level of detectability had on the results of the experiment. The data for these graphs were grouped by speeds for a given level of detectability. This grouping significantly changed the number of mines detected and encountered but also the distances at which each occurred. At a high level of detectability 80 percent of the first mine detections occurred prior to and within 20 meters after the vehicle entered the minefield. This same 80 percent level was increased to 180 meters into the minefield in low detectability trials. Even the gap between the two curves on each graph is further apart for high detectability trials as compared to the lower level, although the gap decreases as the speed of the tank increases. As stated earlier, the level of detectability had a significant effect on the probability of encountering a mine, but examination of these graphs indicates that the distances traveled into the minefield before an encounter occurred were not dependent on this detectability factor.

(b) These same two cumulative distance curves when taken in regard to density levels as in figures 9, 10, and 11 reemphasize these trends. One can see that as density increases distance both to first detection and to first encounter becomes shorter regardless of the level of detectability.

(3) Tables 9 and 10 list the average distance to first mine detection ($\bar{x}_{D1}$), average distance to first and subsequent mine encounters ($\bar{x}_{Ei}$), and, finally, the average path length traversed ($\bar{x}_p$) for each trial cell in meters. Below each value is the number (n) of first detections and encounters that occurred. The distance to second, third, fourth, and fifth encounters were all calculated from the previous encounter rather than a cumulative distance from the edge of the minefield.

7. **SUMMARY.** Of the three factors tested--detectability of mines, speed traveled through the minefield, and the density of that minefield--all had an effect on the probability of detecting a minefield and the probability of detecting and avoiding a mine. The detectability of the mines had the greatest effect on the data. A 10 to 12 mile per hour speed

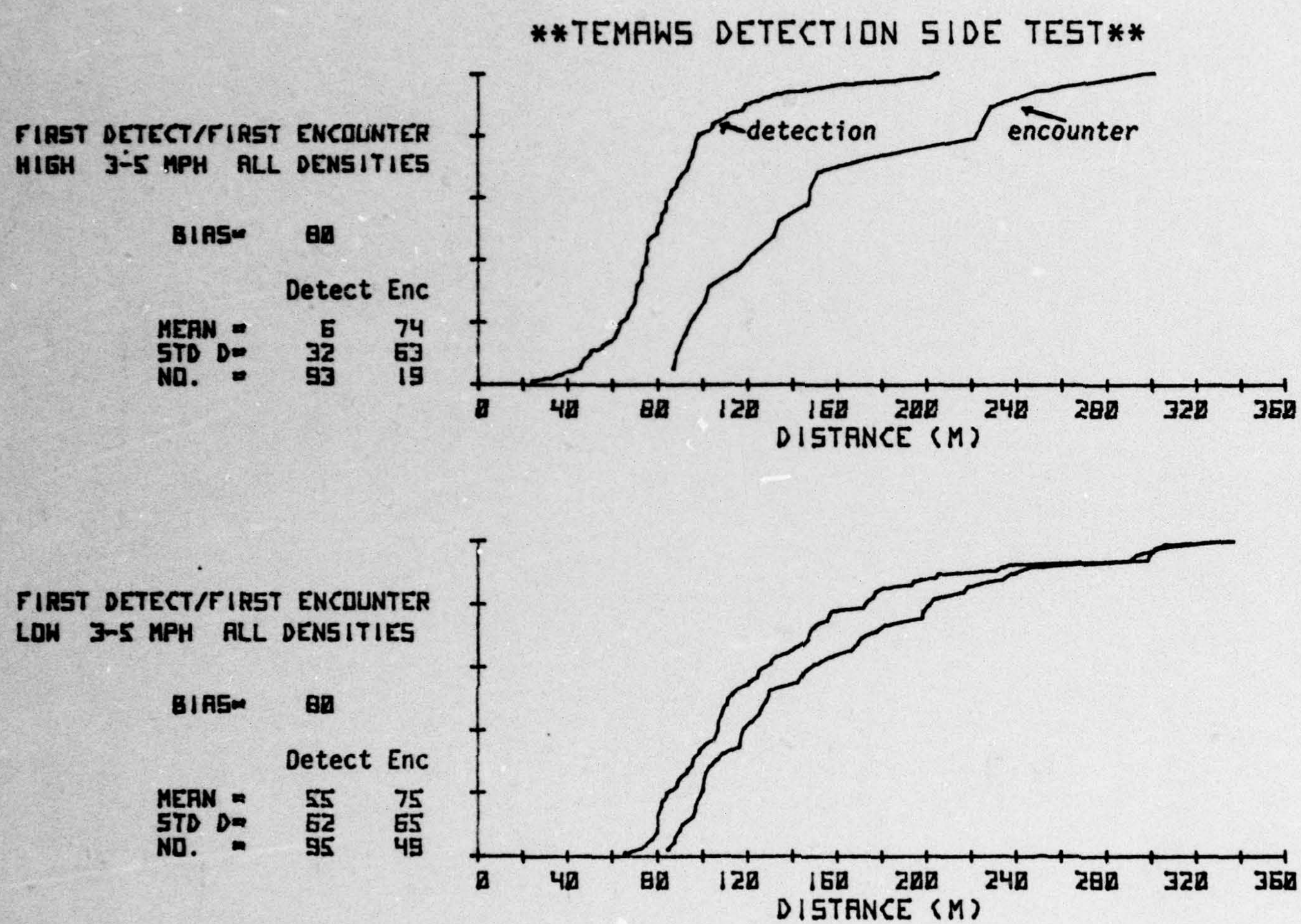

Figure 6. Cumulative distances to first detection and first encounter for 3 to 5 miles per hour, high and low detectability levels

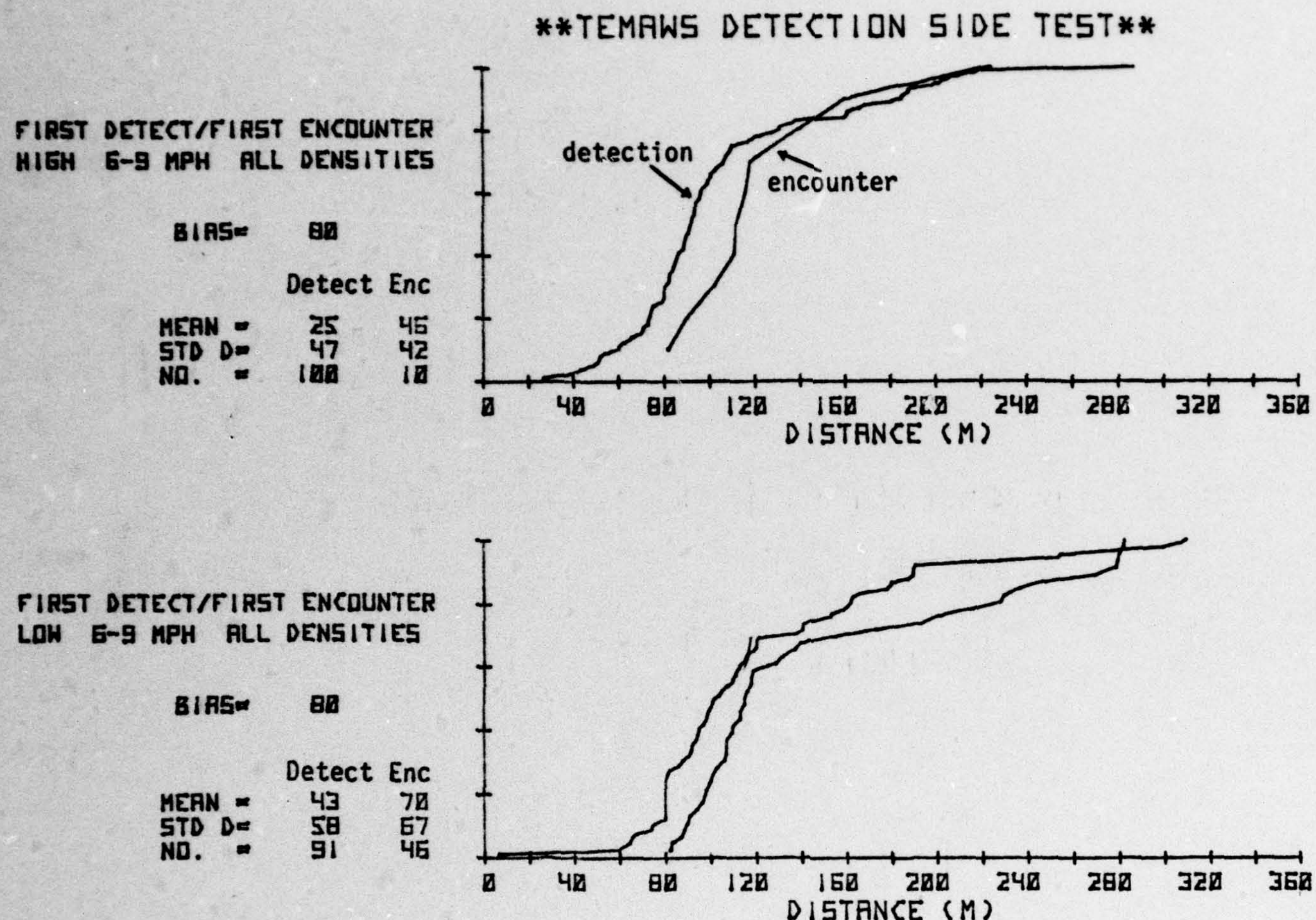

Figure 7. Cumulative distances to first detection and first encounter for 6 to 9 miles per hour, high and low detectability levels

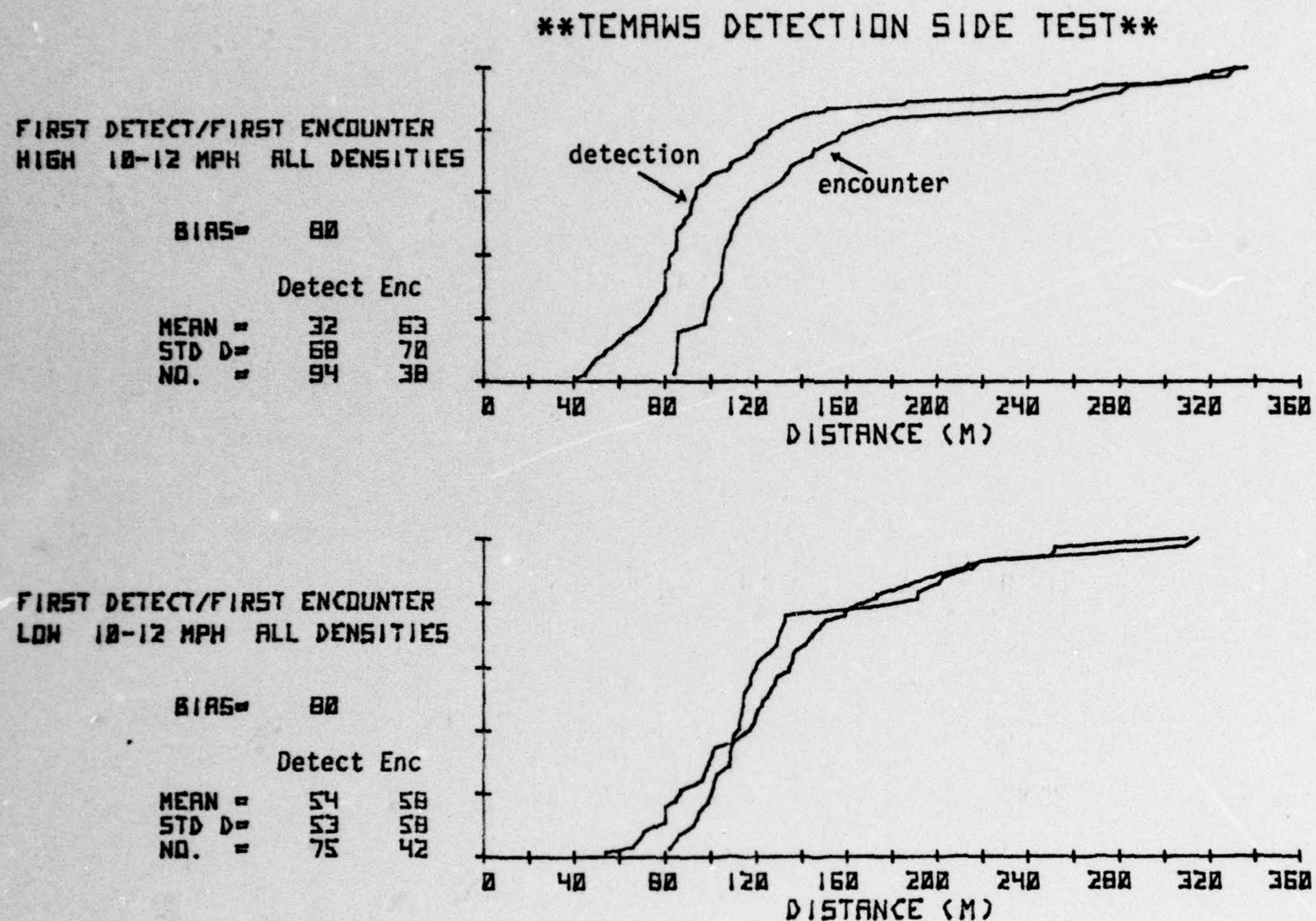

Figure 8. Cumulative distances to first detection and first encounter for 10 to 12 miles per hour, high and low detectability levels

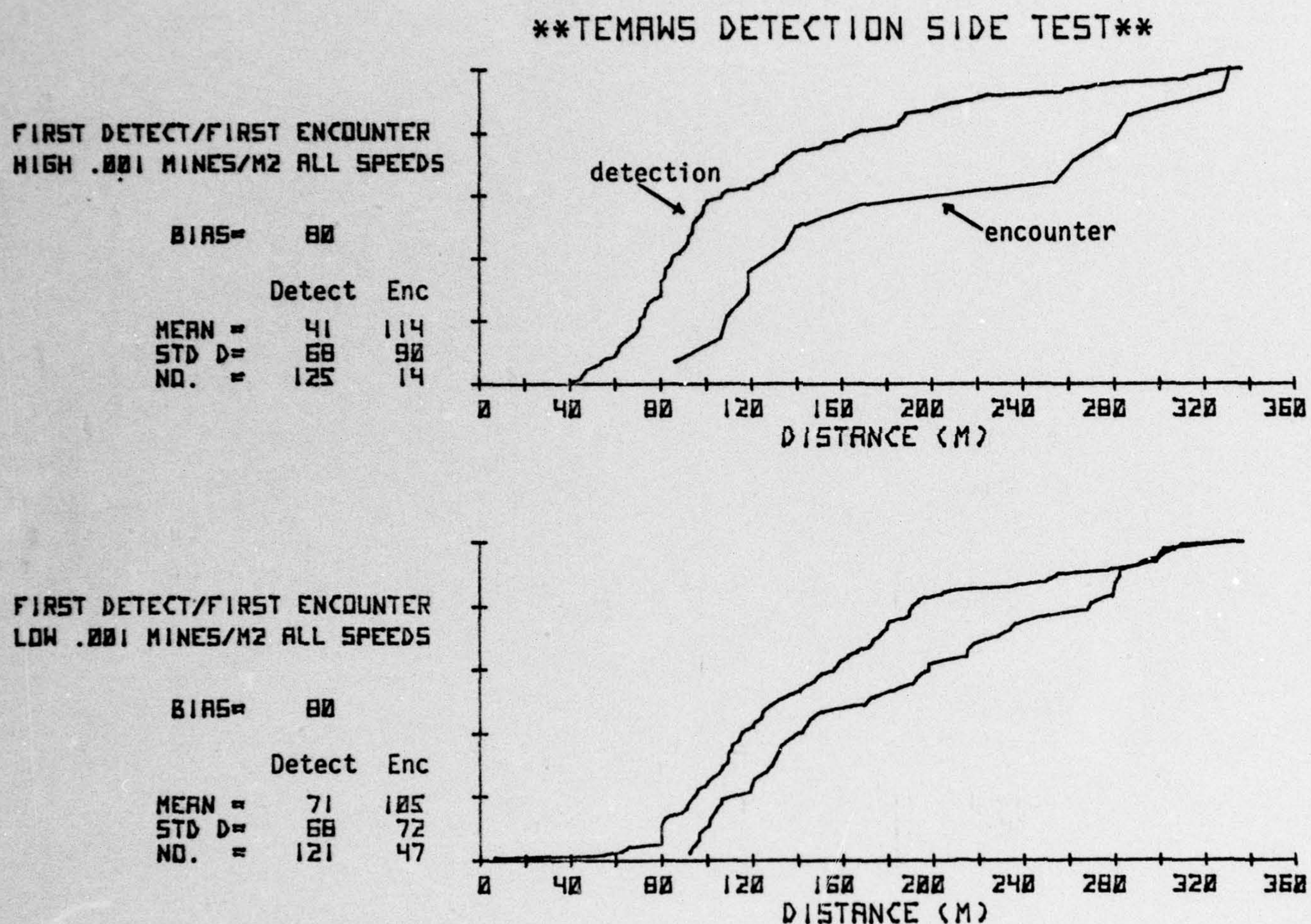

Figure 9. Cumulative distances to first detection and first encounter for .001 mines/m^2, high and low detectability levels

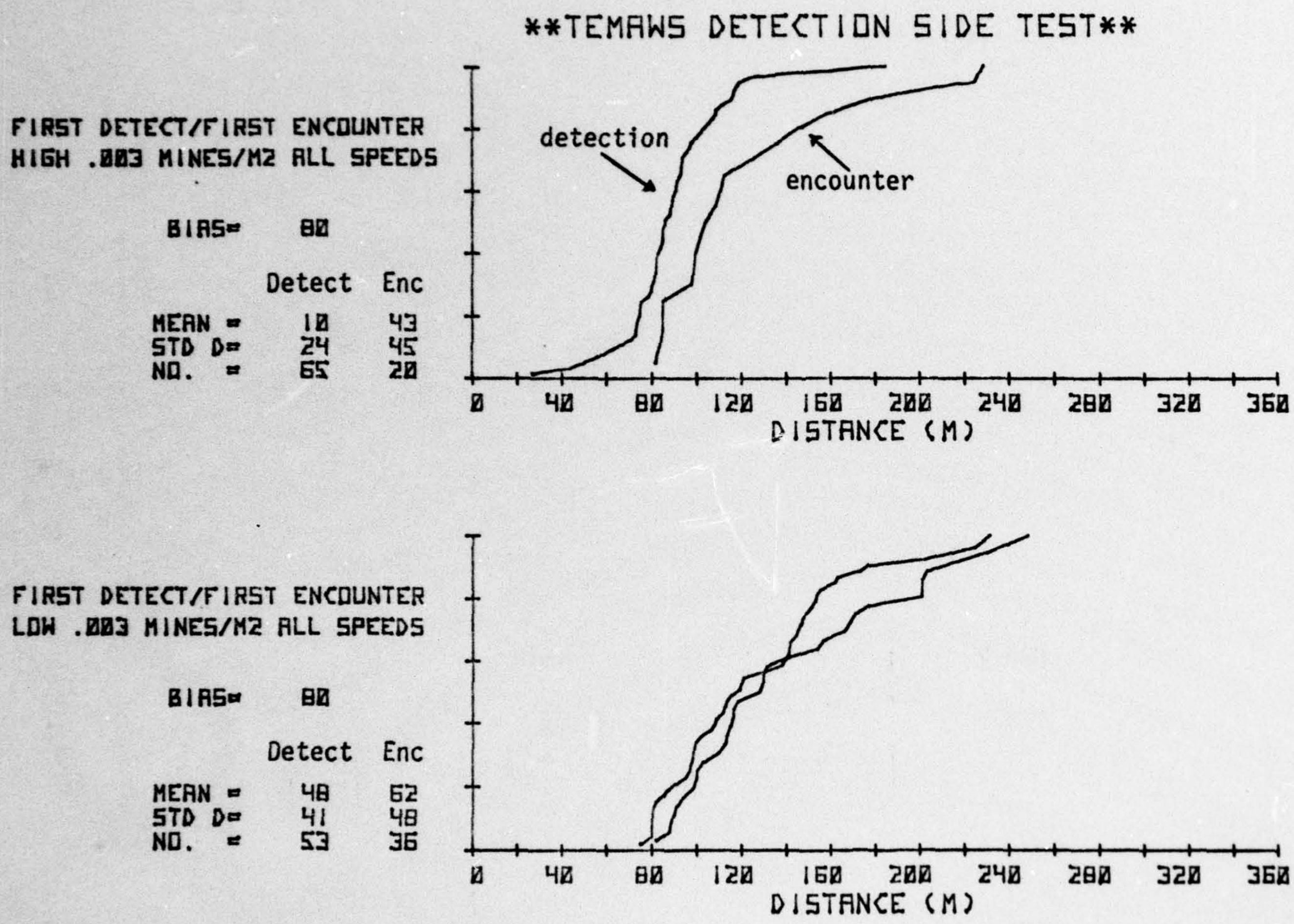

Figure 10. Cumulative distances to first detection and first encounter for .003 mines/m^2, high and low detectability levels

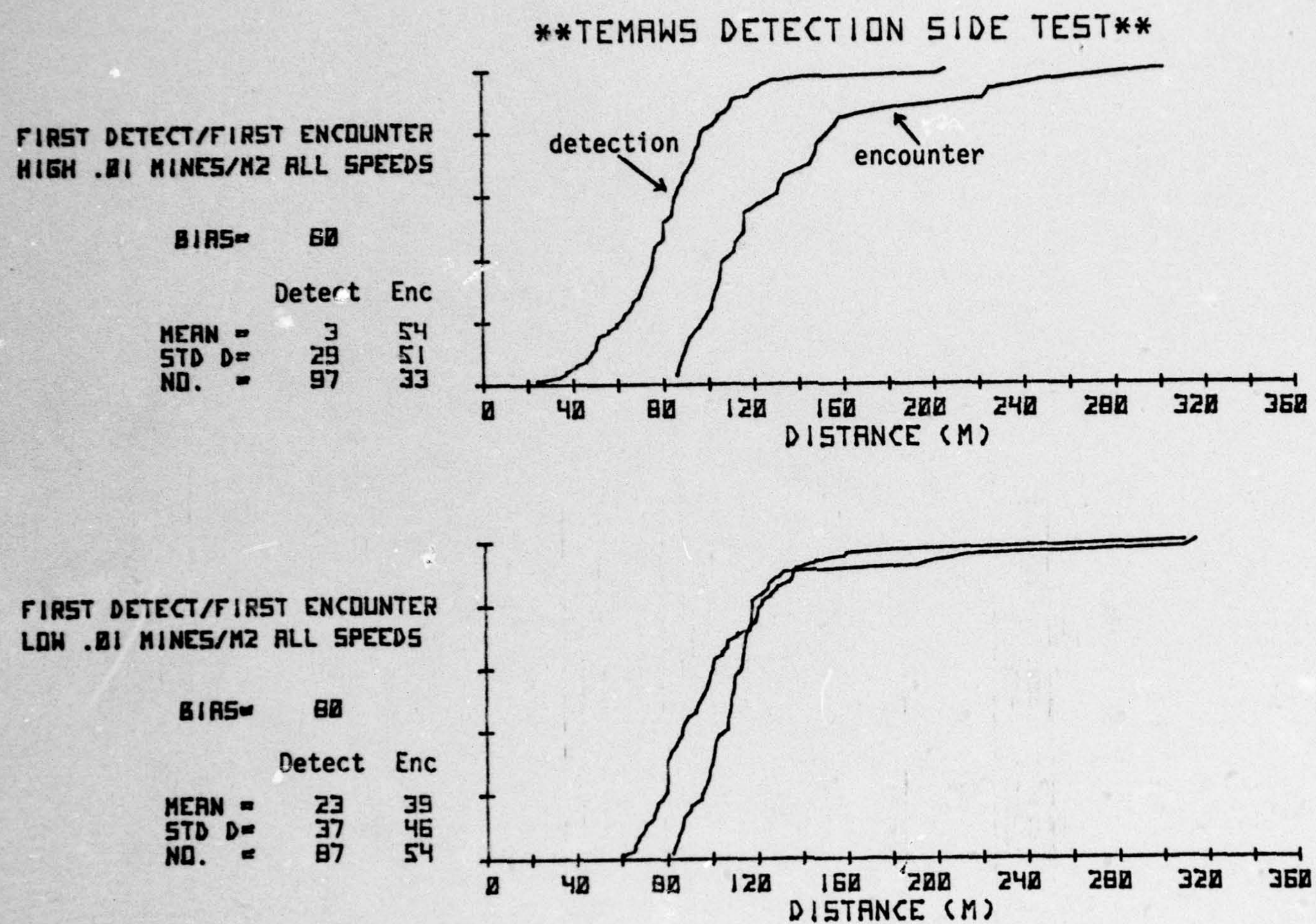

Figure 11. Cumulative distances to first detection and first encounter for .01 mines/m^2, high and low detectability levels

Table 9. High detectability, distance to first detection and all encounters (meters)

	.001 mines/m^2						
speed (mph)	$\bar{x}_{D1}$ n	$\bar{x}_{E1}$ n	$\bar{x}_{E2}$ n	$\bar{x}_{E3}$ n	$\bar{x}_{E4}$ n	$\bar{x}_{E5}$ n	$\bar{x}_{P}$ n
3-5	2.6 (26)						255.4 (26)
6-9	37.9 (51)	48.9 (2)					254.6 (51)
10-12	55.9 (48)	125.4 (12)	95.5 (3)				259.1 (53)

	.003 mines/m^2						
speed (mph)	$\bar{x}_{D1}$ n	$\bar{x}_{E1}$ n	$\bar{x}_{E2}$ n	$\bar{x}_{E3}$ n	$\bar{x}_{E4}$ n	$\bar{x}_{E5}$ n	$\bar{x}_{P}$ n
3-5	4.9 (13)	148.8 (1)					173.4 (13)
6-9	8.5 (27)	55.9 (5)	42.1 (2)	62.0 (1)			180.1 (27)
10-12	9.7 (25)	30.7 (14)	51.1 (5)	24.3 (3)	147.4 (1)		173.4 (25)

	.01 mines/m^2						
speed (mph)	$\bar{x}_{D1}$ n	$\bar{x}_{E1}$ n	$\bar{x}_{E2}$ n	$\bar{x}_{E3}$ n	$\bar{x}_{E4}$ n	$\bar{x}_{E5}$ n	$\bar{x}_{P}$ n
3-5	4.1 (54)	70.0 (18)	23.5 (6)				172.2 (54)
6-9	-1.0 (22)	25.9 (3)	24.2 (1)				63.9 (22)
10-12	-4.2 (21)	38.3 (12)	9.8 (6)	18.2 (2)			62.6 (21)

Table 10. Low detectability, distance to first detection and all encounters (meters)

	.001 mines/m^2						
speed (mph)	$\bar{x}_{D1}$ n	$\bar{x}_{E1}$ n	$\bar{x}_{E2}$ n	$\bar{x}_{E3}$ n	$\bar{x}_{E4}$ n	$\bar{x}_{E5}$ n	$\bar{x}_{P}$ n
3-5	79.9 (52)	103.9 (21)	89.9 (11)	47.5 (2)	11.4 (1)		257.9 (53)
6-9	83.7 (45)	122.4 (17)	68.0 (3)				257.9 (49)
10-12	74.4 (23)	57.0 (12)	112.2 (1)				251.1 (24)

	.003 mines/m^2						
speed (mph)	$\bar{x}_{D1}$ n	$\bar{x}_{E1}$ n	$\bar{x}_{E2}$ n	$\bar{x}_{E3}$ n	$\bar{x}_{E4}$ n	$\bar{x}_{E5}$ n	$\bar{x}_{P}$ n
3-5	41.9 (22)	71.2 (17)	31.8 (10)	38.6 (3)	29.9 (2)		172.2 (26)
6-9	45.3 (21)	56.0 (14)	66.5 (8)	.6 (3)			173.6 (25)
10-12	72.9 (9)	51.1 (5)	80.8 (2)	68.3 (1)			173.3 (13)

	.01 mines/m^2						
speed (mph)	$\bar{x}_{D1}$ n	$\bar{x}_{E1}$ n	$\bar{x}_{E2}$ n	$\bar{x}_{E3}$ n	$\bar{x}_{E4}$ n	$\bar{x}_{E5}$ n	$\bar{x}_{P}$ n
3-5	59.4 (21)	24.1 (11)	10.4 (5)	17.8 (2)	4.9 (1)		54.1 (26)
6-9	11.7 (23)	22.4 (15)	8.9 (6)	8.6 (2)	4.7 (2)	11.3 (1)	63.3 (26)
10-12	34.9 (43)	53.9 (28)	66.2 (13)	93.9 (2)	9.0 (1)		161.6 (61)

lowered the driver's probability of detecting the minefield and his probability of detecting and avoiding a mine in his immediate path. An anomaly in the data was the driver's increased ability to detect minefields at the lowest density (.001 mines/square meter). In theory, the opposite should have occurred. No explanation for this result is apparent. Another interesting result was the apparent random effect of the density level on the driver's ability to detect and subsequently avoid a mine in his path. The results at each density level seem independent of what would be expected; that is, a decrease in the probability as the density increased. The results gave a considerably higher probability of detection and avoidance at the .01 mines/square meter density level than at the .003 level. Even though all factors influenced the detection and avoidance of mines, only the level of detectability was found to affect one of the main objectives of a minefield--probability of encounter.

8. CONCLUSIONS. The results of the TEMAWS II experiment and data analysis indicate a minefield's greatest lethality occurs when the mines are at their lowest level of detectability. A .40 probability estimate of encounter appears to be independent of the density of the minefield at this low detectability level although it does tend to increase with higher densities. An increase in the speed of a vehicle through the minefield also tends to increase the encounter rate although not enough to be statistically significant. Driver comments contradict this result; they found it harder to maneuver and avoid mines at the slower 3 to 5 miles per hour speed, but higher speeds lowered their ability to detect mines in the first place. Caution must be used in applying the results from this experiment. The data were collected from a best case situation. At no time were the drivers distracted from their main purpose of detecting and avoiding mines. Data collected with drivers under the added strain of following specific tactical appraoches, avoiding enemy fire, and being concerned with tank crew internal coordination and communication might be substantially degraded compared to the data that were collected from TEMAWS II. Also the lack of vegetation and flat terrain of the test sight may have contributed to higher estimates of the probabilities than one would find under heavier vegetated areas and more rugged terrain.

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APPENDIX A

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